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The Very Large Hadron Collider (VLHC)

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Introduction

After the termination of the SSC in 1993, the US high energy physics community entered into a period of mourning and introspection not unlike that following the death of a close friend. Much of our attention was then drawn to the developing new accelerator at CERN, the Large Hadron Collider (LHC) and continuing the physics programs at Fermilab and SLAC. The Drell Panel, the major high energy physics advisory committee to the Department of Energy, issued a report in 1994 on the future directions of the US program

> **"The LHC will be a great step on the energy frontier, but it will not be the last step. Compelling questions surely lie beyond the physics reach of the LHC. Participation by the US in the LHC would further strengthen our position among world leaders in the development of strategies and mechanisms needed for global cooperation on large-science projects. This would enhance US capabilities to host such projects, including those of high-energy physics.**
>
> **The technology of the LHC does not exhaust the possibilities for proton storage rings. Preliminary examination indicates that it may be technically feasible to build a proton collider with beam energies up to ten times those of the LHC with technology that could be developed during the next decade. For the US to maintain its place among the leaders of the world high-energy physics community, it will be important to participate in regional or global collaborations to carry out the research and development required for such a future machine."**

A VLHC informal study group started to come together at Fermilab in the fall of 1995 and at the 1996 Snowmass Study[1] the parameters of this machine[2] took form. The VLHC as now conceived would be a 100 TeV hadron collider. It would use the Fermilab Main Injector (now nearing completion) to inject protons at 150 GeV into a new 3 TeV Booster and then into a superconducting pp collider ring producing 100 TeV c.m. interactions. A luminosity of $\sim 10^{34}$ $cm^{-2}s^{-1}$ is planned. Our plans were presented to the Subpanel on the Planning for the Future of US High-Energy Physics (the successor to the Drell committee) and in February 1998 their report stated

> **"The Subpanel recommends an expanded program of R&D on cost reduction strategies, enabling technologies, and accelerator physics issues for a VLHC. These efforts should be coordinated across laboratory and university groups with the aim of identifying design concepts for an economically and technically viable facility"**

The coordination has been started with the inclusion of physicists from Brookhaven National Laboratory (BNL), Lawrence Berkeley National Laboratory (LBNL), and Cornell University. Clearly, this collaboration must expanded internationally as well as nationally. The phrase "economically and technically viable facility" presents the real challenge.

Directions

Is a 100 TeV collider too great an energy step? Figure 1 shows an updated version of the famous "Livingston" plot [3]. This plots the energy achieved (on a log scale) by an accelerator as a function of the date of its "first announcement". It was noted that in the period 1930 to 1960 there was an average ten fold increase in energy every six years. It was also commented in the original 1962 presentation that "this may lag by many months the actual date of operation". Certainly, by current time scales this seems an optimistic statement. For a colliding beam accelerator (none were in existence for the original plot), the equivalent fixed target energy to reach the comparable center of mass energy was plotted. My additions to this plot use a line to indicate the construction/planning period. The deceased SSC is included with a dashed line. For the VLHC, the equivalent fixed target accelerator would need a 5 EeV ($5 \cdot 10^{18}$ eV) proton beam! The average ten fold increase in energy every six years, still seems to be reasonably accurate.

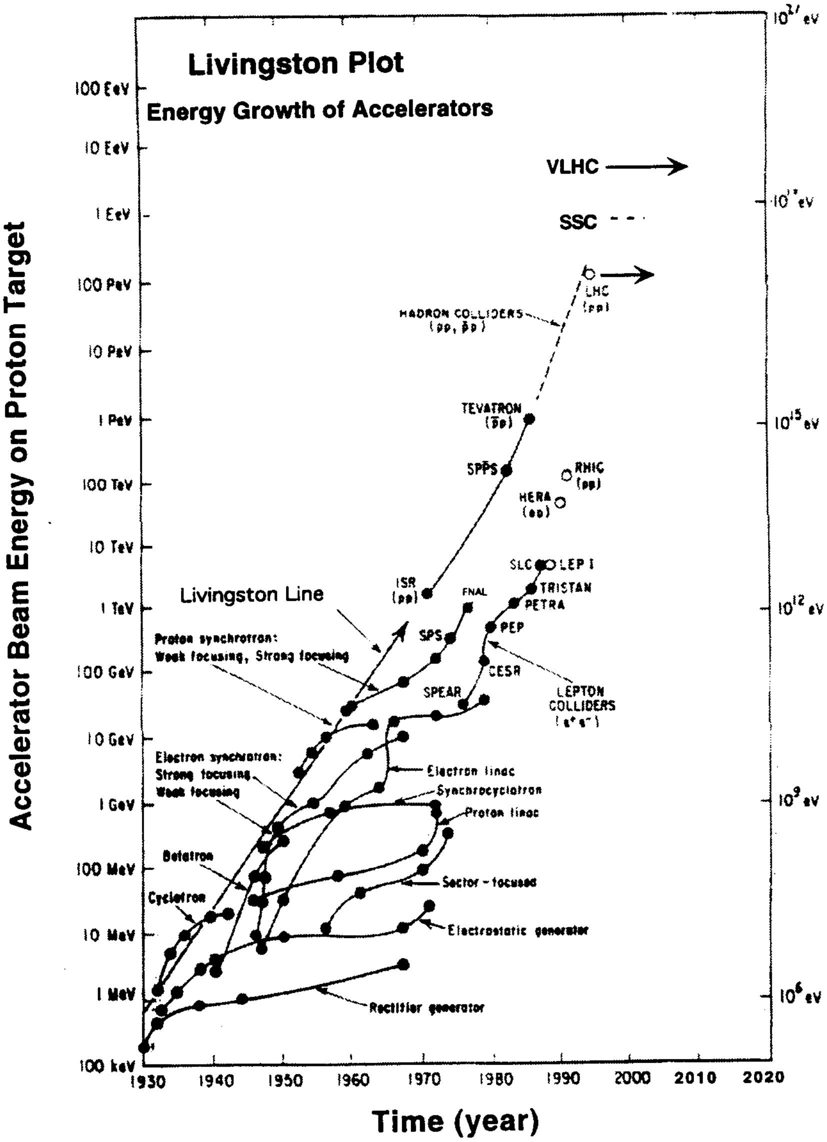

Figure 1
Livingston Plot

This optimism was incorporated into the poster for the Very Large Hadron Collider Physics and Detector Workshop [4] which showed Enrico Fermi's sketch of an accelerator that circled the earth. The workshop addressed the question of why the VLHC? Hadron colliders have traditionally been "discovery machines" which probe the highest reaches of the energy frontier. This was evident once more in the workshop reports[4].

•New strong dynamics that might be manifested in EW symmetry breaking. Such new dynamics as well as new physics associated with flavor physics might have a rich structure in the 1-10 TeV range.

•Supersymmetry mediated by new gauge bosons might make their appearance in the 1-10 TeV range.

•Exotics such as scalar lepto-quarks which might appear in the Tevatron at 250 GeV and at the LHC at 1.5 TeV would probe up to ~7 TeV at the VLHC.

•New W' and Z' which might be seen by the Fermilab colliding beam detectors at energies up to ~700 GeV would go up to ~25 TeV at the VLHC.

•The compositness scale could be extended from Λ_c ~10-15 TeV for the LHC to about 100 TeV for the VLHC

•Diffractive physics soft and hard QCD processes, full rapidity investigations. The higher energy is expected to provide new insights into these old questions.

This new physics which excites our imagination, but has not yet been glimpsed, comes with a somewhat uncertain energy scale. This contrasts with the Bevatron whose energy was chosen to just comfortably confront the existence of the antiproton. A whimsical Mother Nature might put these goals beyond even the VLHC reach.

New approaches will be required to continue the dramatic rise in collider energies represented by the Livingston plot. Ahead will be some years of intensive and challenging research and development needed to fully establish feasibility and make credible cost estimates.

This will be built on Fermilab's proven core competence in accelerator research, construction and operation, superconducting magnet technology, and its experience as a major international scientific laboratory. It further expands on the existing multi-billion dollar investment in Fermilab facilities and most importantly its people.

How might one build a VLHC and keep the cost ($/TeV) within reason? In rethinking the balance of component costs a number of points became evident.

•Large $/ft cost of high field magnets at SSC and LHC
•Lower field (2.0 T) superconducting magnets have much lower costs/ft

===> New design for VLHC magnet

•Tunnel costs not the major cost driver
•Explore reductions in tunnel costs
•Excellent Northern Illinois geology
•Extensive local tunneling experience
•Quiet seismic region

•3 TeV Booster would be needed

==> 3 TeV Booster as a test bed for new VLHC concepts.

This also led to the focusing of the Fermilab VLHC efforts into 4 teams co-ordinated by E. Malamud. They (and their leaders) are Accelerator Physics (S. Mishra), Accelerator Systems (G. W. Foster), Construction/Installation (J. Lach), and Physics/Detectors (D. Denisov).

Transmission Line Magnet

The transmission line magnet [5] is a simple but elegant approach due to G. W. Foster and has the potential of reducing the magnet costs very significantly. Shown in Figure 2, it utilizes a 2-in-1 warm-iron superferric design whose excitation is by a

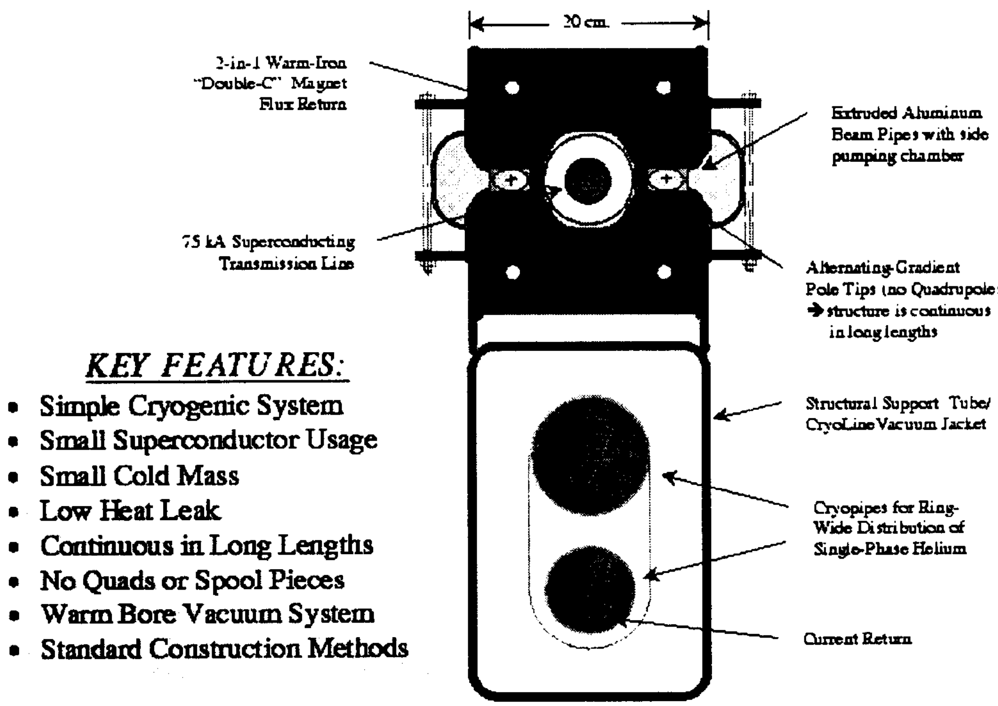

Figure 2
The Transmission Line Magnet

single turn conductor carrying 75 kA. This one turn provides the current for the magnet which guides **both** beams of the collider. Because the field shape is determined by the iron pole tips of the "Double-C" magnet design, the field is limited to ~2 T; hence, a very large circumference (hundreds of km) would be needed for the 50 TeV beams.

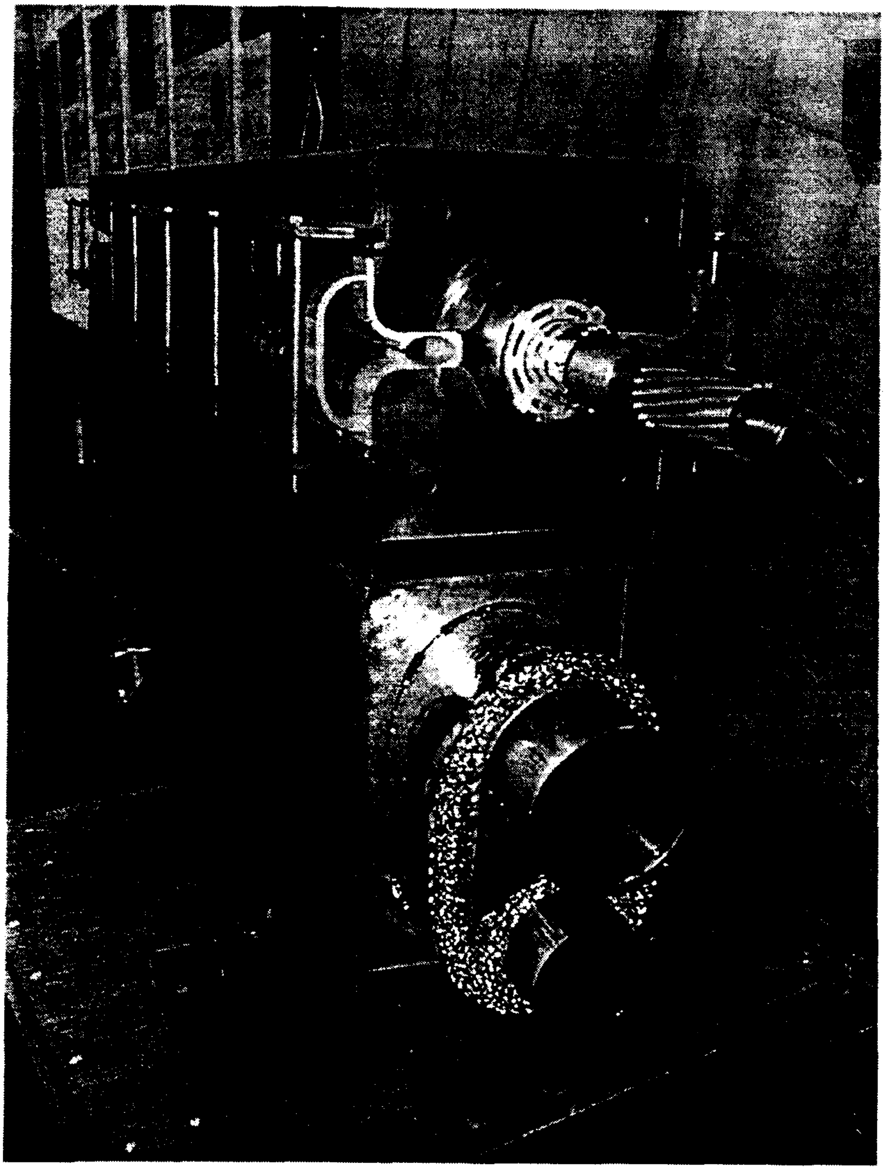

Figure 3
Transmission Line Magnet
2 m prototype.

A 2 m prototype has been completed (Figure 3) and tested. Listed among its key features in Figure 2 is that it can be constructed in long lengths. A 50 m prototype is now under construction. Since all correction and focusing elements are integral to the magnet, it offers the possibility of construction in lengths limited only by our ability to transport them effectively to and in the tunnel. Note that the magnet with its pole tips, beam pipes, vacuum chambers, and transmission line fits in a cross section only somewhat larger than 20 cm. The width of VLHC tunnel will be determined not by the magnet size but by the space needed for tunnel construction, and for installation and service of accelerator components.

Illinois Setting and Tunneling

The northern Illinois geology is characterized by surface deposits composed of a series of glacial tills. Below these deposits is rock sedimentary rock layers, mostly dolomites, deposited when the area was a vast inland sea. This region extends from Fermilab to the Mississippi River and would provide a suitable environment for the VLHC tunnel. There is extensive tunneling experience in these strata. The Metropolitan Water Reclamation District of Greater Chicago has constructed about a hundred miles of rock tunnels in these sedimentary dolomite layers for water conveyance projects.

The region is free of earthquake and volcanic activity and has no active faults. Recent seismic measurements[6] indicate very low background seismic activity. This extensive set of measurements was done at both the Fermilab Tevatron (which is built on surface glacial tills) and in tunnels in the dolomite rock layers 300-400 ft below the surface. In this report, the measurements are compared with the needs of the VLHC as well as any possible future muon collider and electron collider projects. Effects due to on-surface noise sources are less in deep tunnels, though still visible. Careful engineering of mechanical supports, of vacuum, power and cooling systems should be an important part of R&D efforts to decrease the level of vibrations

The 3 TeV Booster

An intermediate accelerator would be needed to "boost" the Main Injector beam energy before injecting it into the VLHC ring. This smaller and more manageable machine would serve as a useful study [7] for the accelerator and tunneling technologies needed for the much larger VLHC ring. In the last few decades there have been gradual improvements in tunneling technologies which resulted in reduced cost/ft of tunnel. We expect these improvements to continue so that at the time of construction of the VLHC tunnel the costs will be further reduced. While the cost for the Booster tunnel may be acceptable, the extrapolated cost for the much longer VLHC tunnel is sufficiently large that it may preclude its funding.

The Booster layout, shown in Figure 4. has a 34 km (21.1 miles) circumference. It can be approximated by two 15.2 km semi-circular arcs connected by two 1.8 km straight sections. This layout is based on using 2.0 T magnets to bend the proton beams. The tunnel is bored through the Galena-Platteville dolomite rock formation at an elevation of 97.5 m (320 ft) above mean sea level (msl). At the Fermilab site, this is about 128 m (421 ft) below the ground surface.

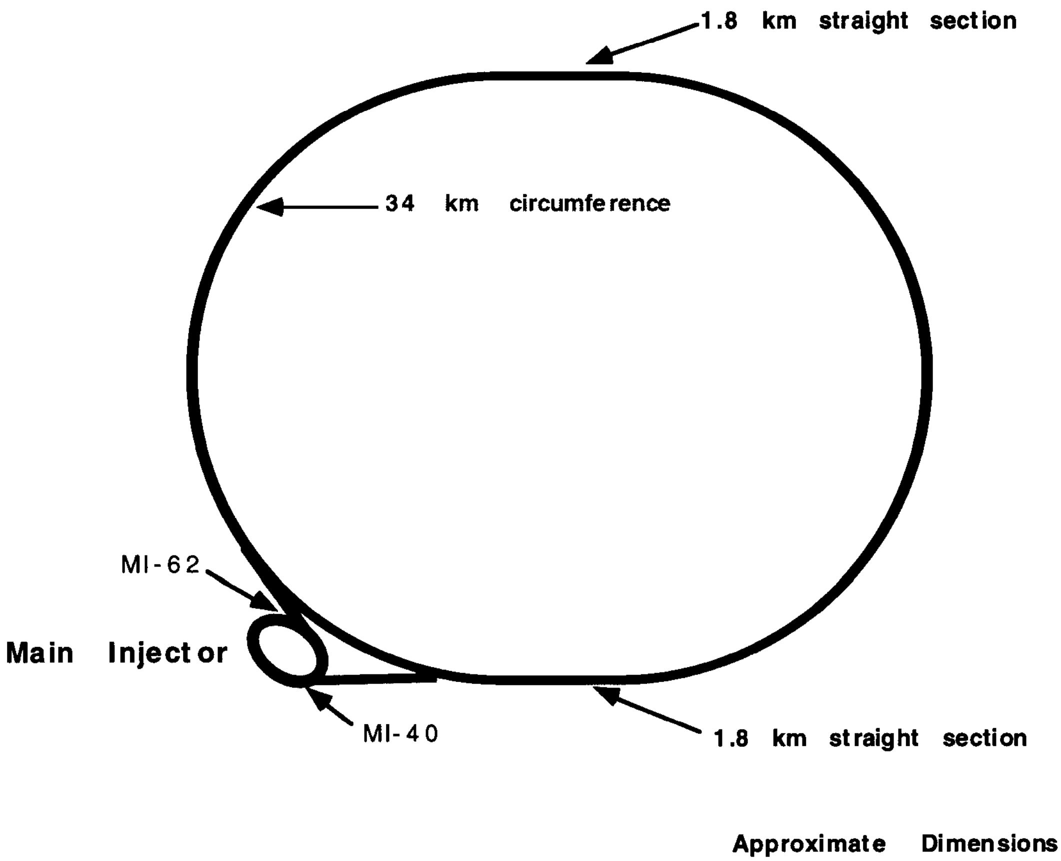

Figure 4 Booster Configuration

An experienced tunneling contractor was asked to prepare a "non-competitive bid" on the above tunnel configuration and also provide us with his detailed back up cost estimates. A tunnel diameter of 12 feet was chosen as the most cost effective size. The tunnel cost per ft is insensitive to the diameter within a range of about 12-14 ft. Here one balances the reduced cost and higher rate of rock excavation using a smaller tunnel with the spatial constraints of transporting the spoils to the surface. The proposed tunnel excavation uses two tunnel boring machines (TBMs) for mining and long conveyor belts (about 5 miles) for the removal of spoils. Among the insights provided was that about 1/2 of the cost was due to labor. Cost reduction or better performance of one item may not directly translate into a cost reduction or better performance of the entire project. This is illustrated by the balance that is needed in the performance of the TBM and the muck removal apparatus. This study has produced a "base line" tunnel cost which will serve as a comparison for future potential cost reductions.

Conclusions and Future Goals

- **Produce detailed designs and cost estimates for a 3 TeV (low-field) and 3 TeV (medium field) boosters**
- **Find ways to lower the cost/meter of tunnel by 2x**
- **Continue to develop concepts for a 100 TeV c.m. pp collider built in the Fermilab region using either low or high field magnets**
- **Begin work on a high-field magnet**
- **Carry out prototype work on all components of the low-field machine**
- **The 3 TeV Booster can be considered as a Tevatron replacement with higher energy and lower operating costs**
- **The 3 TeV Booster will test our ability to build a machine that extends off site**
- **It will be a rapid-cycling injector for the larger machine**
- **Is there a physics program for a 3+3 TeV Colider?**
- **It could be a new benchmark of HEP's ability to construct machines with much lower cost/TeV**

Furthur information on the progress of the VLHC can be found by browsing the Fermilab computer site: http://www.fnal.gov/

"Particle Accelerators" by Livingston and Blewett[3] ends with the still very appropriate quote by Browning "Ah, but a man's reach should exceed his grasp, or what's heaven for?"

I wish to thank the other members of the VLHC study group for their many discussions and insights. The very warm hospitality of the organizers is acknowledged and appreciated. This work is supported by the US Department of Energy under contract DE-AC02-76CH03000.

References

1. New Directions for High Energy Physics, Snowmass, CO, 1996. Proceedings Joint DPF/DPB Summer Study, A.P.S.
2. M. Harrison *et al.,*, New Directions for High-Energy Physics, Snowmass, CO, p 125 of the Proceedings.
3. M.S. Livingston and J.P. Blewett. Particle Accelerators, McGraw-Hill Company, Inc., 1962.
4. VLHC "Yellow Book", March 1997, Copies of transparencies from Physics and Detector Workshop, Fermilab March 13-15, 1997.
5. VLHC "Turquoise Book", January 1988, Compiled by S. Mishra.
6. B. Baklakov et al, Ground Vibration Measurements for Fermilab Future Collider Projects, Submitted to Phys Rev. 1998
7. J. Lach, P. Conroy, C. Laughton, E. Malamud, Cost Model For a 3 TeV Booster Tunnel, Fermilab TM-2048 (1998)